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An fMRI study of expert musical imagery: To what extent do imagined and executed performance share the same neural substrate

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Mental rehearsal is advocated as an expert learning strategy. Our research explores the neural basis of the type of multi-modal musical imagery employed by expert pianists. We have developed functional neuroimaging paradigms to investigate musical imagery in more detail, in order to examine the reported benefits of mental rehearsal as an expert learning strategy. We report here on our preliminary findings.

Keywords: fMRI; music; imagery; Middle Frontal Gyrus; learning

Expert musicians use integrated auditory, motor, and visual imagery during learning and performance (Holmes 2005). Mental rehearsal of these images may to some extent replace or supplement physical training (Driskell *et al.* 1994) and has, therefore, been proposed as a means of reducing physical overuse, enhancing memorization and reducing anxiety (Freymuth 1999).

Previous research suggests that imagery and performance engage many of the same neural regions, but that there are also a number of differences in brain functional organization, alluding to potentially interesting differences in cognitive processing (Lotze *et al.* 2003, Meister *et al.* 2004). Although some of the benefits of imagery have been demonstrated through the empirical and qualitative study of elite musicians (Clark *et al.* in press), more research is needed to examine effective strategy choice and to understand the mechanisms via which imagery reportedly enhances performance.

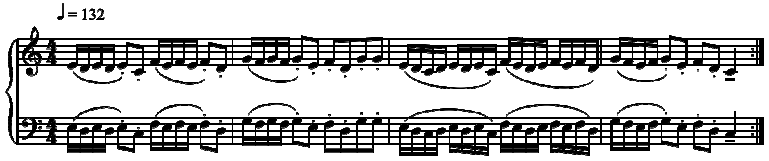

Figure 1. Musical stimulus used in the study.

The aim of this study was to develop neuroimaging paradigms to investigate multi-modal musical imagery performed by expert pianists.

METHOD

Participants

Healthy volunteer professional and advanced student pianists, with a minimum of 10 years of training, were recruited for the study.

Materials

Participants memorized a novel musical extract prior to scanning (Figure 1) by mentally rehearsing the sound and structure as well as playing the extract on a keyboard (with auditory feedback). Before scanning it was demonstrated that the music could be played and imagined at the correct speed. The extract was limited to a single hand and arm position in order to avoid arm movement during scanning; the unison material was designed to be easy to memorize, with the repeated use of 3rd and 4th fingers at speed presenting a slight motor challenge.

Procedure

We scanned expert pianists during imagery and simulated motor performance of the memorized extract. During both conditions, the sound of the music was imagined. When instructed to "imagine," the participant was asked to mentally recreate the sound of the music and a sense of performing it. When instructed to "play," the participant was asked to mentally recreate the sound, the sense of performance, and to move the fingers as if playing on a real piano.

We used a block design, contrasting either imagined or simulated playing with rest (18 s active blocks interspersed with 18 s fixation rest blocks). Each run lasted for six minutes. During the functional scans, written instructions

were presented on a screen. A 3T whole-body scanner (Verio, Siemens, Erlangen, Germany) was used for image acquisition. 118 Functional volumes were acquired using an interleaved EPI gradient echo sequence (TR/TE/flip angle=3000 ms/30 ms/90°, slice thickness=3 mm, 36 slices, FOV=24 cm, matrix size=64×64). All data were analyzed using BrainVoyager QX (Brain Innovation, Maastricht, The Netherlands).

RESULTS

Figures 2-4 show results for a 42 year-old professional pianist who began training at the age of 6. The pianist reported vivid sound imagery throughout, with an accompanying image of finger movements; visual imagery of the keyboard was also present to some extent. With the exception of primary motor cortex (M1), which was activated only during simulated performance, the motor system of the brain was activated similarly for both imagery and simulated performance of the piano extract (i.e. bilateral premotor [BA6], SMA, and cerebellum). Similar regions in the inferior parietal lobe were also activated bilaterally during both tasks. The notable difference between the imagined and simulated performance conditions was that the former produced bilateral activation of the Middle Frontal Gyrus (MFG) whereas the latter produced only left sided activation of MFG.

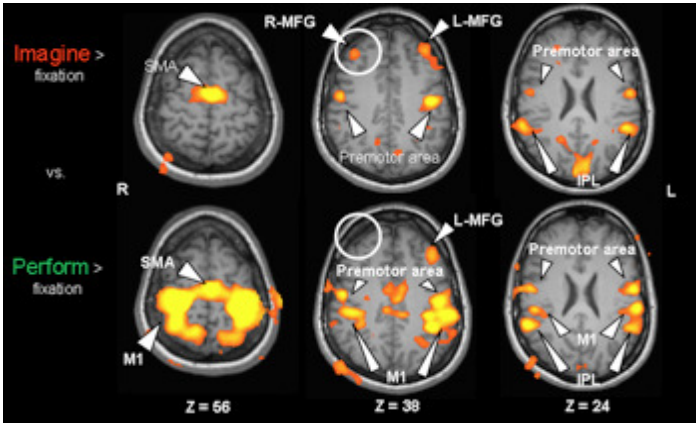

Figure 2. Significantly activated regions for imagery and performance (both versus fixation, N=1, corrected $p<0.05$, cluster threshold=10 voxels). (See full color version at www.performancescience.org.)

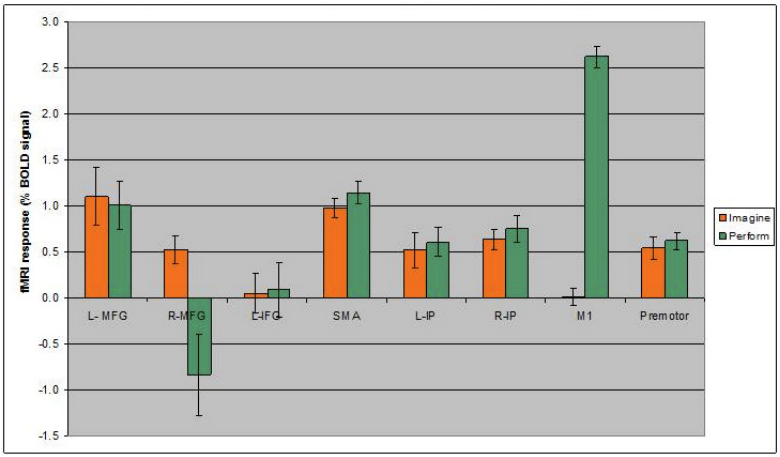

Figure 3. Average % BOLD signal of regions of interest.

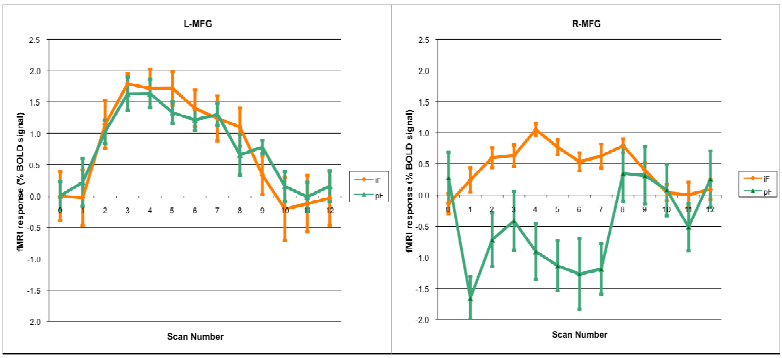

Figure 4. Time course of the BOLD signal: L-MFG and R-MFG. (See full color versions at www.performancescience.org.)

DISCUSSION

As expected for this pianist who reported vivid sound and movement imagery skills, the pattern of activation for performed and imagined piano music was similar, with the motor system of the brain showing similar activation during both conditions. The exception, as predicted, was that the primary motor cortex (M1) was activated only during performance (Lotze *et al.* 2003). In

addition, motor performance showed left sided activation of the MFG, while performance imagery showed bilateral activation of the MFG. We interpret this finding in terms of a possible shift, or change in level, of attention to internally generated representations of musical content during imagery as compared with performance. In other words, imagery may engage similar processes to execution but specifically allow access to cognitive processes that are not as readily accessible during performance.

The MFG is thus a potential neural substrate for musical imagery and could provide an index to monitor the effectiveness of imagery as a learning strategy. We are in the process of scanning a cohort of pianists in order to investigate this hypothesis.

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